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Identification of the photovoltaic model parameters using the crow search algorithm

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Abstract: Photovoltaic (PV) systems are widely used for several many decades. They have become an important source for green energy and they are currently used in many applications. The PV industry has grown because of the improvements in the technology of converting light into electrical energy as well as the cost reduction. This project investigates the applications of crow search algorithm (CSA) in accurately identifying the PV module parameters. CSA is a novel population-based meta-heuristic optimiser based on the intelligence crows' exhibit in their behaviours, which helps them identify best location to state their catcher. In this study, the CSA is simulated using MATLAB environment and it is performed on the single diode and double diode PV models to estimate their parameters with minimum output power error. This error can be said to be the difference between the maximum output power and the calculated power output at a particular solar irradiance and cell temperature values.

1 Introduction

Solar photovoltaic (PV) generators are parts of the renewable energy sources which are pollution free, noise free, long life, no moving parts, simple design and short installation time [1–4]. Solar cells transform the solar radiation incident on their surfaces to give a direct current electricity. Presently, the deployment and installation of PV generators is rapidly increasing and broadly serving as an effective source of green and clean energy in comparison to other electricity sources. Accurate parameters of the PV module equivalent circuit are required to study PV generator performance under the various operating conditions of temperature variations and solar irradiations. PV cells can be demonstrated by two common models: the single diode model and the double diode model [5]. The former is simpler and has quite a close performance to the latter. The single diode model contains the following five unknown parameters: the diode ideality factor (a), the photo-current (I_{PV}), the saturation current (I_o), the parallel connected resistance (R_P) and the series connected resistance (R_S) [6].

The three main parameters of the single diode PV model are: a, R_P, and R_S. Its remaining parameters I_{PV} and I_o can be derived from the model equations [3]. The four main parameters for the double diode model are: first diode factor (a_1), second diode factor (a_2), R_P and R_S [3], while the other parameters, the first PV current (I_{PV1}), the second PV current (I_{PV2}) and I_o are calculated from the model equations [7].

This project presents a novel approach centred on the crow search algorithm (CSA) and it aims at ascertaining the module models' unknown parameters with high precision and fast convergence. The CSA is simulated using MATLAB environment. The cost function used with both models is the difference between the expected power and that calculated with CSA. Kyocera KC200GT solar module is used in both parameter identification cases [5].

2 PV module models

2.1 Single diode model

The equivalent circuit of the single diode model is shown in Fig. 1. The circuit consists of: a current source I_{PV}, a diode, a parallel-connected resistance R_P and a series-connected resistance R_S [3].

The current–voltage (IV) characteristics of a PV module are mathematically expressed by this non-linear equation below [3]:

$$I = I_{PV} - I_0\left[\exp\left(\frac{V + R_S I}{a V_T}\right) - 1\right] - \frac{V + R_S I}{R_P}$$
$$V_T = \frac{N_S \cdot K \cdot T}{q} \tag{1}$$

where V_T denotes the thermo-electromotive force (EMF) of the PV module. N_S denotes the numerical size of the PV cells wired in series. K stands for Boltzmann constant. T denotes the module's temperature (Kelvin), and q denotes the charge of an electron [8].

The IV characteristics give three combinations of I and V and its value, they are always provided by the PV module manufacturers on its datasheet. They are: the short circuit current I_{sc}, the open circuit voltage V_{oc} and the maximum power point MPP. I_{PV} depends basically on the solar irradiance level and the ambient temperature, mathematically it is expressed as

$$I_{PV} = \left(I_{PV.n} + K_I \Delta T\right)\frac{G}{G_n} \tag{2}$$

where $I_{PV.n}$ is the photo-current produced by the PV cell at the nominal condition of irradiation of 1000 W/m^2 and temperature 25 °C, K_I is the cell's temperature coefficient for the short- circuit current, ΔT denotes the change in temperature from the value and the nominal value, G denotes the actual solar irradiation incident on the module's surface, G_n denotes the solar irradiation incident at the normal conditions [9, 10]. $I_{PV\cdot n}$ is shown in the following equation:

$$I_{PV.n} = \frac{R_P + R_S}{R_P} I_{sc.n} \tag{3}$$

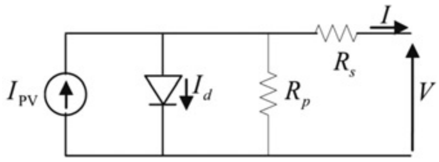


Fig. 1 *Single diode model circuit*

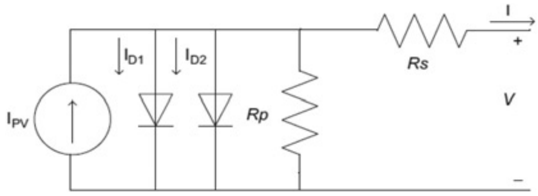


Fig. 2 *Double-diode model equivalent circuit of PV*

The saturation current of the diode I_o is intensely temperature dependent and it can be approximately modelled using the following equation:

$$I_0 = \frac{I_{sc.n} + K_I \Delta T}{\exp\left(\left(V_{oc.n} + K_v \Delta T\right)/aV_t\right)} \tag{4}$$

where $I_{sc.n}$ denotes the rated short-circuit current at nominal condition, $V_{oc.n}$ is open circuit voltage, K_v denotes the short-circuit current temperature coefficient [11, 12].

From (2) and (4), it can be seen that the single diode PV model's three unknown parameters can be reduced to: a, R_S and R_P, while the other unknowns can be derived from the model equations [3, 13].

2.2 Double diode model

The double diode model can be represented by two diodes connected in series to increase voltage or in parallel to increase the current for more accurate representation of PV module. Such arrangements of PV modules are referred to as an array. The PV cell with two diodes model is electricity modelled as shown in Fig. 2.

The PV module of double diode model is depicted in Fig. 2. The non-linear IV characteristic of the PV module, which has a non-linear form, can be expressed as

$$\begin{aligned} I = I_{PV} - I_{O1}\left[\exp^{\left((V+R_S I)/a_{V_t}\right)-1}\right] \\ - I_{O2}\left[\exp\left(\frac{V+R_S I}{a_{V_t}}\right)-1\right] - \frac{V+R_S I}{R_P}\right] \end{aligned} \tag{5}$$

where I_{O1} and I_{O2} are the non-linear reverse current values of the two diodes. V_{T1} and V_{T2} are the thermal voltages (EMFs) of two diodes, a_1 and a_2 are the diodes constants.

The four main parameters of double diode PV model are: a_1, a_2, R_S and R_P, while the other parameters are calculated from the model equations [14].

3 Problem formulation

The research challenge under study in this paper can be derived with the assumption that the maximum output power $P_{max,m}$ generated by the PV module [10] is consistent with the maximum experimental output power $P_{max,e}$ provided on the datasheet at the maximum power point [3, 10]. The goal of the formulated challenge is to reduce the 'power error'. The power error can be defined as the difference value between the desired reference power and the calculated maximum power [3]. It can be written as follows:

$$P_{max.n} = V_{mp}\left\{\left[I_{PV} - I_0\left(\exp^{\left((V_{mp}+R_S I_{mp})/aV_T\right)}\right) - 1\right] - \frac{V_{mp} + R_S I_{mp}}{R_P}\right\} \tag{6}$$

This research paper shows how the CSA technology is performed on an objective function with the 'power error'. This is done in order to determine the unknown parameters of the PV module models [3]. This error is defined as the difference between the references desired for power and the calculated maximum power [15].

4 Crow search algorithm

The CSA is a new optimisation method that tries to obtain an optimal solution from all the available and possible solutions [16]. It is instated the position of a run of N crows in the hunt space and the position of the memory of each crow. The procedure of optimisation of the CSA is as follows:

(i) Initialise problem and adjustable parameters of CSA flock size (N), maximum number of iterations, flight length and awareness probability (AP) are valued [16].
(ii) Initialise and evaluate the crow's position and memory as follows:

$$\text{Crows} = \begin{bmatrix} x_1^1 & x_2^1 & \cdots & x_d^1 \\ x_1^2 & x_2^2 & \cdots & x_d^2 \\ \vdots & \vdots & \vdots & \vdots \\ x_1^N & x_2^N & \cdots & x_d^N \end{bmatrix}$$

(iii) Evaluate fitness (objective) function as follows:

$$\text{Memory} = \begin{bmatrix} m_1^1 & m_2^1 & \cdots & m_d^1 \\ m_1^2 & m_2^2 & \cdots & m_d^2 \\ \vdots & \vdots & \vdots & \vdots \\ m_1^N & m_2^N & \cdots & m_d^N \end{bmatrix}$$

(iv) Generate new position.
(v) Check the feasibility of new positions [16].
(vi) Evaluate fitness function of new positions [16].
(vii) Update memory as follows:

$$m^{i.\text{iter}+1} = \begin{cases} m^{i.\text{iter}} f\left(X^{i.\text{iter}+1} \text{is better than } f\left(m^{i.\text{iter}}\right)\right. \\ m^{i.\text{iter}} 0.w \end{cases} \tag{7}$$

(viii) Check termination criterion.

When the termination criterion is the optimal position of the memory in terms of the objective function value is presented as the solution to the optimisation problem [16]. The flowchart of CSA approach is shown in Fig. 3.

CSA is proposed in this paper. CSA is population-based enhancement calculation which has simple parameters, which thus makes attractive for applications, and the parameter is used to regulate the algorithm's diversity [16, 17].

The results of the CSA are compared with the results presented in the literature and most techniques have used direct control [16]. In this research study, the change in the CSA's fitness function value is less in comparison to the tolerance value already specified [3, 18].

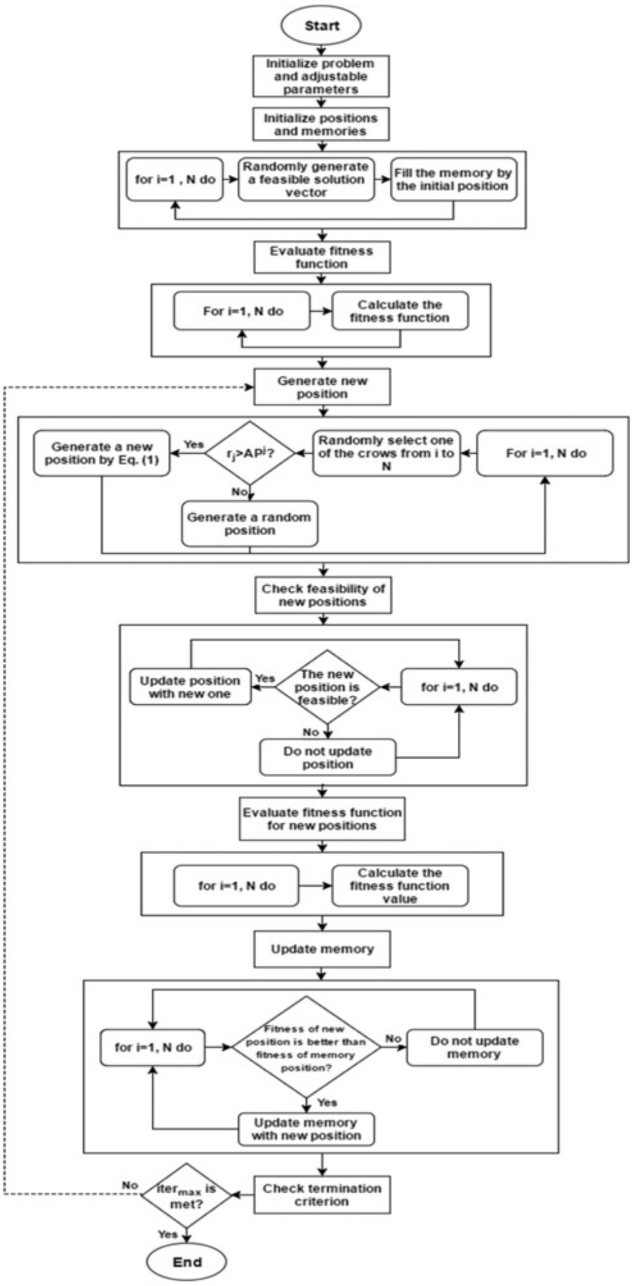


Fig. 3 *Flowchart of CSA for performing optimisation*

5 Simulation results

The PV modules used in testing the CSA-based PV model are Kyocera multi-crystal KC200GT solar Cell [3, 19]. The typical electrical characteristics of these modules were observed at the standard test conditions (STC) (temperature of the module 25 °C, 1.5 air mass and 1000 W/m^2 irradiance) [3].

5.1 Single diode PV model

According to the CSA presented in fourth section of this paper, the parameters that influence the performance of the CSA can be written as in Table 1.

The proposed PV model based on CSA is validated by comparing the results of the simulations and the results of the experimental procedures under various environmental conditions [3].

The current versus voltage graph plots, power versus voltage graph plots and the data results of the experiments carried out on the KC200GT module at various temperature levels are shown in Figs. 4*a* and *b* [3].

Table 1 Comparison of optimal values of unknown parameters at STC for single diode PV module

Method	I_{PV}, A	I_O, A	R_S, Ω	R_P, Ω	a
iteration [19]	8.214	9.825×10^{-8}	0.22	415.41	1.3
proposed SFLA [3]	8.214	7.506×10^{-8}	0.23	405.26	1.28
proposed CSA	8.21	7.389×10^{-8}	0.23	441.12	1.19

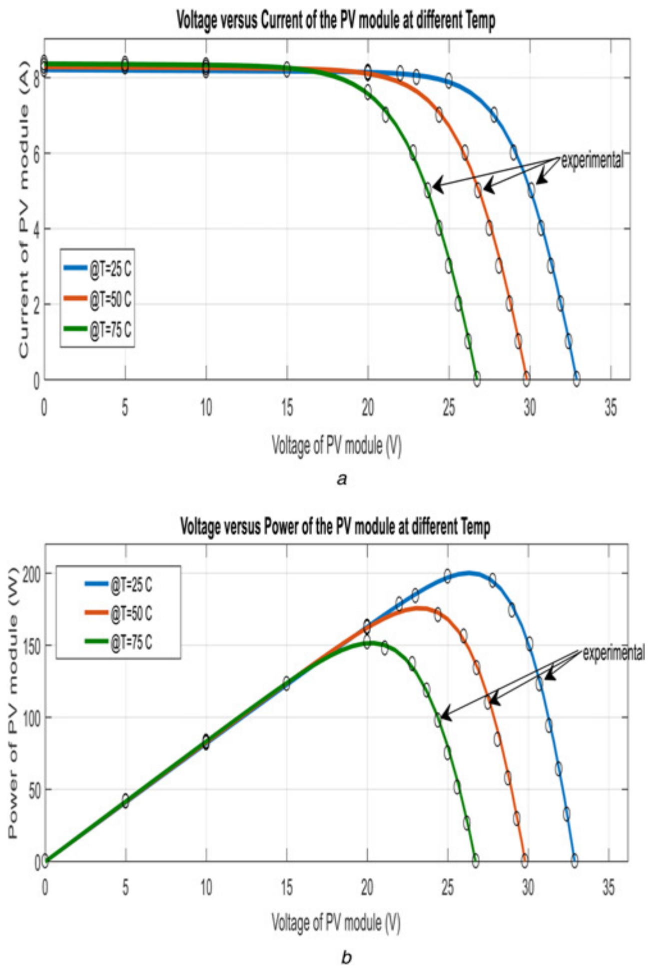


Fig. 4 *Data results of the simulations and the data results of the experiments carried out on the KC200GT module at the various temperature conditions, G = 1000 W/m^2*
a Current versus voltage graph plots
b Power versus voltage graph plots

Figs. 5*a* and *b* show the results of the simulated proposed model and the data results of the experiments done on this PV module at various irradiance levels [3].

This indicates the justification of the validity of the novel CSA-based PV model. This also shows that the simulation results of the proposed PV model using the CSA correlates closely with the experimental data [3].

Fig. 6 demonstrates a comparison of the absolute current error values for the KC200GT PV modules with iteration method: shuffled frog leaping algorithm (SFLA) method and CSA [3]. It can be seen clearly that the values of 'absolute current error' for

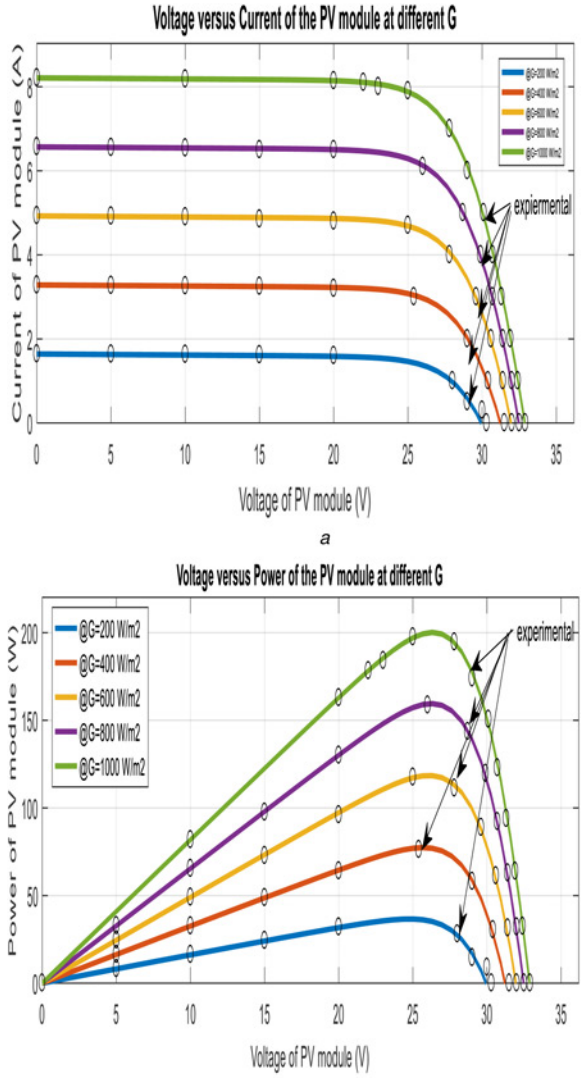


Fig. 5 *Results of the simulation and data results of the experiments done on the KC200GT PV module at different irradiance levels with the temperature constant at 25°C*
a Current versus voltage graph plots
b Power versus voltage graph plots [3]

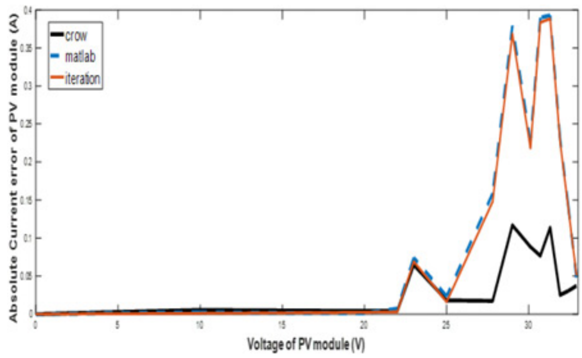


Fig. 6 *Absolute current error graph plot of the single diode model*

the CSA-based PV model is lesser in comparison to the value for other PV models. Therefore, this proposed CSA model is superior to these models [3].

Fig. 7 presents the fitness function convergence for the single diode model.

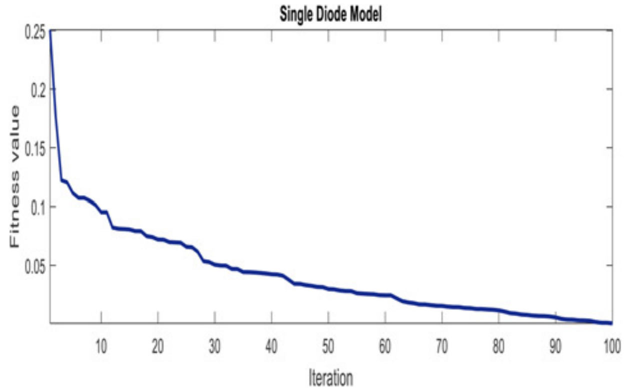


Fig. 7 *Fitness function convergence*

Table 2 Comparison of the optimal values of the unknown parameters of the proposed double diode model carried out under standard test conditions [3]

Method	GA	CSA
I_{PV}, A	8.21	8.21
I_{O1}, A	2.15×10^{-8}	1.73×10^{-8}
I_{O2}, A	4.13×10^{-10}	5.75×10^{-10}
R_S, Ω	0.3	0.02
R_P, Ω	334	342.146
a_1	1.35	1.3009
a_2	1.3	1.2906

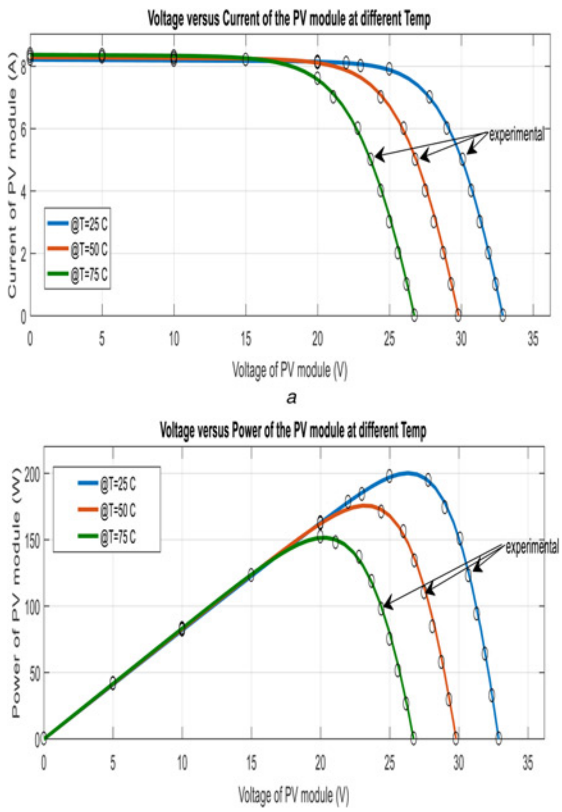
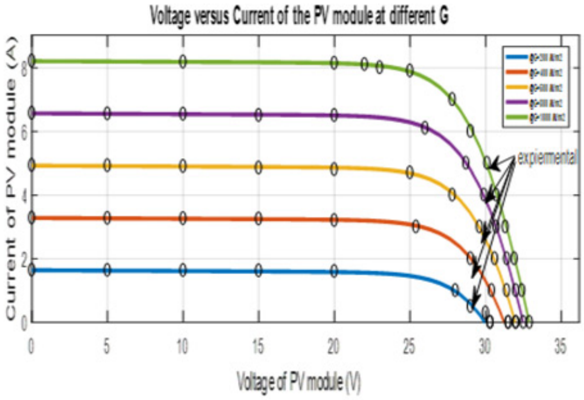


Fig. 8 *Results of the simulation and data results of the experiments done on the KC200GT module at the various temperature levels [3], with irradiance constant at 1000 W/m²*
a Current versus voltage graph plots
b Power versus voltage graph plots for the double diode model [3]



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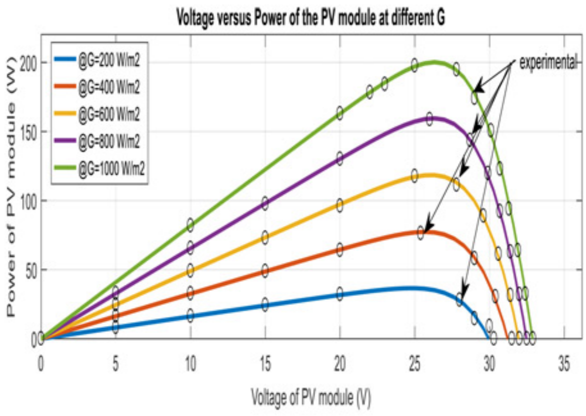

b

Fig. 9 *Results of the simulations and data results of the experiments carried out on the KC200GT module at the various irradiance levels [3], with the temperature constant at 25°C*
a Current versus voltage graph plots
b Power versus voltage graph plots for double diode PV module [3]

5.2 Double diode PV model

According to the CSA presented in Section 4 for a double diode PV model, the unknown parameters that influence the efficiency and accuracy of the CSA can be written as in Table 2.

The proposed CSA-based model in double diode PV model was validated by the comparison of the results of the simulations with the results of the experiments done on the PV modules under various environmental conditions [3].

Figs. 8*a* & *b* depict the current versus voltage graph plots, power versus voltage graph plots and the results of the experiments done on the KC200GT PV module at various temperature levels [3, 20–25].

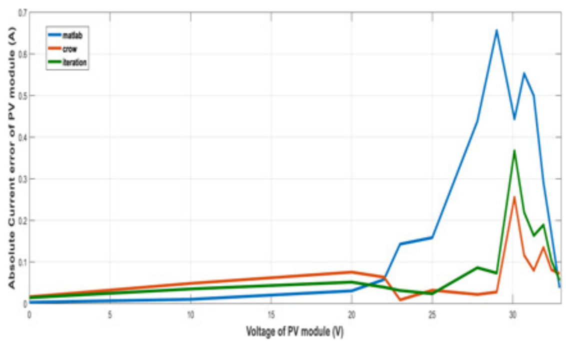

Fig. 10 *Absolute current error graphical plot of a double diode model*

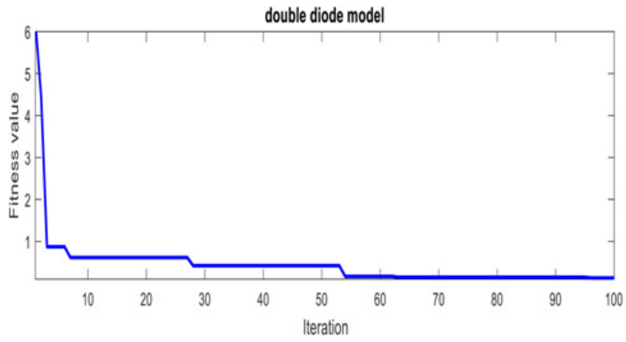

Fig. 11 *Graph of fitness function convergence for double-diode PV model*

Figs. 9*a* and *b* indicate the results of the simulated model and the data results from the experiments carried out on this PV module at various irradiance levels [3].

Fig. 10 indicates a comparison between the absolute current error value of KC200GT modules with the genetic algorithm (GA) method, iteration method of a double diode PV module and CSA [3]. Therefore, it can be concluded that the values of the absolute current error of other PV models are greater in comparison with the CSA-based model [3]. Fig. 11 presents the fitness function convergence for the double diode model.

6 Conclusion

This paper has presented the CSA and its objective was to determine the unknown parameters of the two models for a PV module. The models are the single diode PV model and double diode model [3]. The goal of this research paper is to get the precise PV model that serves a great function in the studies and simulation of PV electricity generating systems [3]. The PV module is expressed by a mathematical model which is basically a non-linear current versus voltage characteristic. The model also has several parameters that are not known due to the datasheets limited information given by the module manufacturers [3]. It is worth knowing that the results of the simulations of the CSA-based PV model match the envisaged results and that the proposed model can be a valuable design basis for PV system designers [3, 7].

7 References

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